*International Journal of Engineering Applied Sciences and Technology, 2023*
**Vol. 8, Issue 08, ISSN No. 2455-2143, Pages 29-33**
**Published Online December 2023 in IJEAST (http://www.ijeast.com)**

# BUILDING-INTEGRATED PHOTOVOLTAICS (BIPV) TECHNOLOGIES AND MODE OF OPERATION

Abigo Izabo
Mechanical & Mechatronic Engineering Department,
Federal University Otuoke, Bayelsa, Nigeria

*Abstract*— **The integration of solar photovoltaic (PV) systems into building structures, commonly referred to as Building Integrated Photovoltaics (BIPV), represents a pivotal innovation in the sustainable energy sector. BIPV technologies seamlessly merge energy generation and building design, offering numerous benefits such as reduced carbon emissions, energy cost savings, and improved architectural aesthetics. This abstract provides an extensive overview of BIPV technologies, exploring their potential to revolutionize the way we generate and consume clean energy within the built environment.**

**BIPV technologies have evolved significantly over the past few decades, spurred by increasing environmental concerns, energy efficiency regulations, and a growing demand for renewable energy sources. This abstract discusses the key elements that define the BIPV landscape, including solar cell types, integration techniques, materials, and architectural applications.**

*Keywords*— **Architectural Solar Integration, BIPV, BIPV-T, CIGS, Grid Integration, Luminescent Solar Concentrators (LSCs), Materials, Perovskite Solar Cells, Solar Facades, Solar Shingles, Solar Windows, Thin-Film Photovoltaics, Tandem Solar Cells:, Watt-Peak (Wp)**

## I. INTRODUCTION

Over the last five years the global photovoltaic systems industry has grown more than 40% annually (Global Solar 2015). According to predictions, PV will deliver about 345 GW by 2020. and 1081 GW by 2030 (Tyagi et al., 2013). Leading technology in making solar cells is silicon, even though many researchers are trying to find new technology to reduce the material costs for production of solar cells, due to high cost of silicone. Thin film technology seems like suitable substitution, but the efficiency of this technology is still low, and researchers are making effort to enhance it. Commercial materials commonly used for PV systems, beside silicon (Si), include solar cells of cadmium telluride (CdTe), coper-indium-di selenide (CIS) and solar cells made of other thin layer materials (Razykov et al., 2011). Flexible modules used in new thin film PV technology give important perspective to PV systems, as these have possibility of simple integration in roofs and building facades. In applications where the weight is important flexible modules are very suitable and offer much faster payback than other conventional photovoltaics, which makes expectation that they will play an important role in the global PV market in the near future (Kessler et al., 2004). Today, solar PV systems totaling more than 3,500 MW have been built worldwide. The cost of PV systems has steadily declined since 1970 (Peters et al., 2019). The use of small-scale residential PV systems has been encouraged worldwide as a result of this price decline. Recent events have prompted environmental experts to launch substantial research initiatives for using renewable energy sources, such as solar energy. The use of solar photovoltaic energy as a source of power is being taken more seriously, which bodes well for the future of this technology (Abigo et al 2012). This contribution's goal is to present the most recent advancements in solar photovoltaic energy systems (Taylor & Klenk, 2018). One of the new strategies to sustain renewable energy in the residential sector is by employing solar power-generating devices or systems known as building-integrated photovoltaics (BIPVs) that are smoothly incorporated into the building envelope and are included in building elements, such as windows, roofs, or façades. BIPV systems, which install PV modules that are integrated into the building envelope, have gained popularity in recent years. They reduce the need for building resources since they make it possible to produce renewable energy locally, and they can replace traditional construction components. BIPV systems have the dual benefits of boosting the potential for renewable energy in the built environment and delivering cost and time savings during construction by displacing conventional building components. BIPVs must deal with the complex challenges of transmission and distribution losses (Fernandes & Reddy, 2020). Therefore, one of the holistic strategies that lessen the need for such enormous land expanses is the incorporation of PV-covered buildings.

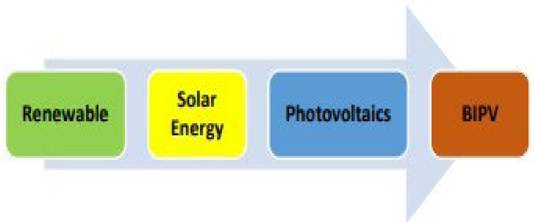
BIPV systems may include shades, rooftops, building awnings, and building facade walls to block sunlight while simultaneously producing auxiliary electrical energy (Traverse et al 2014). Recent advancements in PV technology have produced semi-transparent PV modules, such as thin-film solar panels and bifacial silicon solar panels, allowing some

International Journal of Engineering Applied Sciences and Technology, 2023
Vol. 8, Issue 08, ISSN No. 2455-2143, Pages 29-33
Published Online December 2023 in IJEAST (http://www.ijeast.com)

amount of light and transparency. This makes the BIPV system applicable to skylight applications, windows, and attractive building facades as it allows a good amount of daylight for a building. Thus, BIPV windows have the advantage of simultaneously producing electricity, reducing the amount of energy needed for building cooling or heating and allowing lighting (Wang et al., 2017).

## II. MODE OF OPERATION

Building-integrated photovoltaics (BIPV) are photovoltaic materials that are utilized to replace traditional building materials in areas such as the roof, skylights, or façade. They are increasingly being used in the construction of new buildings as a primary or secondary source of electrical power, though identical technology can be retrofitted into older structures. The advantage of integrated photovoltaics over non-integrated systems is that the initial cost can be covered by reducing the amount spent on building materials and labor that would otherwise be necessary to construct the component of the building that the BIPV modules replace. The majority of BIPV products use on one of two technologies (Tripathy et al, 2016):




1. Crystalline solar cells (c-SI)
2. Thin-film solar cells (TFSC).

C-SI technologies are composed up of wafers of single-cell crystalline silicon that, while more efficient than Thin-Film cells, are more expensive to manufacture. These two technologies' applications can be classified into five types of BIPV products (Tripathy et al, 2016):

1. Standard in-roof systems. These generally take the form of applicable strips of photovoltaic cells.
2. Semi-transparent systems. These products are typically used in greenhouse or cold weather applications where solar energy must simultaneously be captured and allowed into the building.
3. Cladding systems. There are a broad range of these systems; their commonality being their vertical application on a building facade.
4. Solar Tiles and Shingles. These are the most common BIPV systems as they can easily be swapped out for conventional shingle roof finishes.
5. Flexible Laminate. These goods, which are often purchased in thin-sheet form, can be applied to a variety of shapes, notably roof forms.

BIPV products can be applied in a variety of scenarios: pitched roofs, flat roofs, curved roofs, semi-transparent facades, skylights, shading systems, external walls, and curtain walls, with flat roofs and pitched roofs being the most ideal for solar energy capture.
others.

## 6. ZERO-NET ENERGY BUILDINGS WITH BIPV

Zero-net energy buildings (ZNEBs) refer to buildings that are connected to the energy infrastructure, and they produce all the energy that they consume over the year. They form balance between energy taken from and supplied to the energy grid over the year. The “positive net” concept means that the electrical energy supplied to the energy grid is higher than the amount received for one year (Positive-net energy buildings – PNEBs).

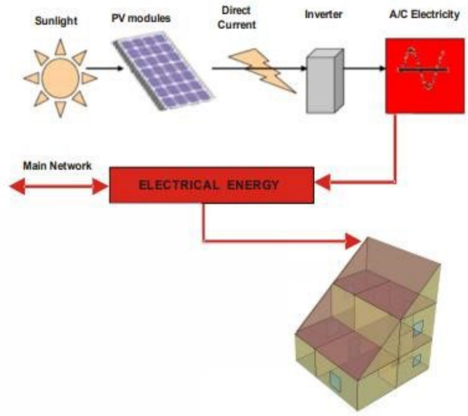



**Figure1.** Zero-Net Energy Building with BIPV module
Source: (Global Solar, 2015)

(Figure 1) shows ZNEB designed with PV panels installed on the roof. Size of PV array limits the amount of generated electricity. If PV system does not satisfy the building needs for electrical energy, the remaining energy is taken from energy network, but if PV system satisfies the building needs for electricity, then the rest of produced energy is fed into the energy grid (Nikolic et al., 2012, Radulovic et al 2013 and Radulovic et al 2014). The system containing PV modules placed on building roof, as well as on building envelopes, is named building integrated PV (BIPV). Nowadays semi-transparent BIPV modules are often used to permit entrance of sunlight to interior of building, maintaining the function of electricity generation. BIPV integrated in building converts from purely electrical device to a construction product. As a construction product, it generates electricity, besides other features, thus replacing commonly used elements like roof, windows, blinds, fac, etc. (Ferrara et al., 2017).
Building-integrated photovoltaic modules are available in several forms:

**International Journal of Engineering Applied Sciences and Technology, 2023**
**Vol. 8, Issue 08, ISSN No. 2455-2143, Pages 29-33**
**Published Online December 2023 in IJEAST (http://www.ijeast.com)**

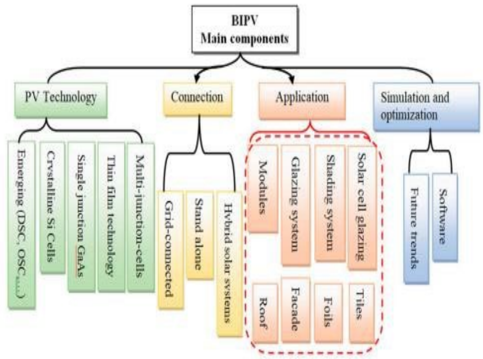



FIGURE 1
Classification of BIPV systems.

Source: (Abojela et al,2023)

Transparent And Translucent Photovoltaics
To conduct electricity out of the cell, transparent solar panels use a tin oxide coating on the inner surface of the glass panes. Titanium oxide is covered with a photoelectric dye in the cell. To create energy, most common solar cells employ visible and infrared light. The ingenious new solar cell, on the other hand, also makes use of UV radiation. The installation surface area might be considerable if used to replace traditional window glass or placed over the glass, leading to prospective uses that take use of the combined functions of power generation, lighting, and temperature control. Transparent photovoltaics are also known as "translucent photovoltaics" since they transmit half of the light that strikes them. Organic photovoltaics, like inorganic photovoltaics, could be translucent.

1. Types of transparent and translucent photovoltaics
2. Non-wavelength-selective

By spatially segmenting opaque solar cells, some non-wavelength-selective photovoltaics attain semi-transparency. This approach places multiple tiny cells on a transparent substrate and employs any form of opaque solar cell. This spacing affects power conversion efficiencies significantly while improving transmission.
Another type of non-wavelength-selective photovoltaics employs visibly absorbing thin-film semiconductors with narrow band gaps that enable light to pass through. This produces semitransparent photovoltaics with a direct trade-off between efficiency and transmission akin to spatially segmented opaque solar cells.

3. Wavelength-selective

Wavelength-selective photovoltaics, which were initially demonstrated in 2011, achieve transparency by using materials that only absorb UV and/or NIR light. Despite increased transmissions, reduced power conversion efficiency has resulted from a number of difficulties. Small exciton diffusion lengths, scaling of transparent electrodes without compromising efficiency, and general lifetime due to the volatility of organic materials utilized in TPVs in general are examples of these.

4. PV TECHNOLOGIES

The materials of PV module types are classified as follows according to (Abojela et al,2023):
Si: More than 90% of modern PV systems use modules made of crystalline silicon. The modules' architecture can vary in minor, yet significant, ways. Due to the widespread usage of crystalline silicon modules, other types of modules may exhibit differences in module designs, but to better follow the development of technology, crystalline silicon module types are divided as detailed in the following text.
Perovskite: these modules are built of materials having the perovskite structure, commonly abbreviated as ABX3, where A denotes an organic or inorganic cation (for example, methylammonium), B denotes a metal cation (generally $Pb^{2+}$), and X denotes a halide (for example, $I^-$ and/or $Br^-$). A hybrid organic–inorganic methylammonium lead halide perovskite is the name given to the structure that is most frequently used. $CaTiO_3$'s crystal structure serves as a representation of the overall perovskite structure.

- OPV (organic photovoltaic technology): bulk hetero-junction modules made of organic and/or polymeric small molecules are used in the majority of OPV technologies. The separation of the photo-induced exciton into free electrons and holes that produce photocurrent is made easier by the bulk heterojunction concept.

III–V: these modules make use of elements from the periodic table's third and fifth columns. Several of these reports are for stacks of multiple layers, often known as multi-junctions, because these materials can be composed of a wide range of band gaps. Because their lattice constants are so comparable, germanium and gallium arsenide are frequently produced together. Modules containing germanium are categorized under this heading for convenience.

- Hybrid: these courses incorporate content from various categories. It consists mostly of a silicon and III–V module combination. In the future, modules manufactured from other material combinations, such as perovskites, may also fall under this category.
- Dye-sensitized: typically, these modules use a porous titanium dioxide matrix coating with a skinny layer of robustly gripping dye. The color absorbs the photocarriers (excitons), and the light is divided at the interface between an electrolyte and titanium oxide, specifically penetrating the titania.
- Chalcogenide: it is a material that has no less than one part of the sixth column of the cyclic table, such as tellurides, selenides, and sulfides. The majority familiar of these is copper indium gallium selenide (CIGS) and CdTe.

**International Journal of Engineering Applied Sciences and Technology, 2023**
**Vol. 8, Issue 08, ISSN No. 2455-2143, Pages 29-33**
**Published Online December 2023 in IJEAST (http://www.ijeast.com)**

- Amorphous silicon: this contains thin-film silicon modules with single, two, and three junctions and is grown on glass or other low-cost sub-materials. Several multi-junction masses include alloys with some partially crystallized and germanium layers to aid get layers with a lesser band gap.

Monocrystalline solar panels are more expensive than polycrystalline solar panels, but this does not necessarily imply that they are not the ideal choice. The silicon structure is the key determinant of the price difference between these two types of solar panels. Manufacturers pour molten silicon into square molds to create polycrystalline panels and then separate the resulting wafers into individual modules. Contrarily, the meticulous control of silicon solidification during the production of monocrystalline panels requires a more complicated procedure, which drives up the cost of single-crystal solar modules. Monocrystalline solar panels often have better efficiencies and include black solar modules built of a single silicon crystal, but the cost of these panels is frequently higher. Multiple silicon crystals that have been fused to form blue solar cells are used in polycrystalline panels.

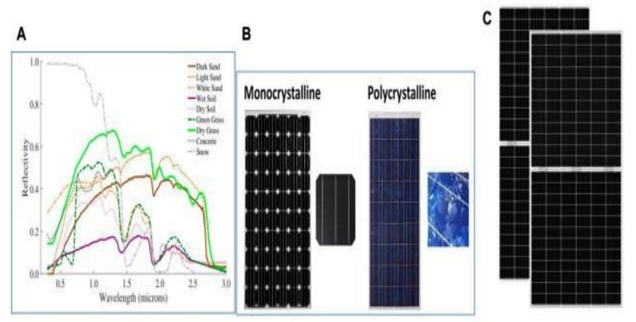



FIGURE 3
**(A)** Reflectivity R (λ) for nine different earth surfaces based on the "SMARTS" dataset (Gostein et al., 2020), **(B)** monocrystalline and polycrystalline silicon solar modules (China P-type Monocrystalline Bifacial Solar Module LYGF-BP72P factory and suppliers | Linyang, 2023), and **(C)** polycrystalline panel bifacial PV with 144 cells.

Source: (Abojela et al,2023):

## III. DISCUSSION

Building Integrated Photovoltaics (BIPV) is at the forefront of sustainable building design and renewable energy solutions. BIPV technologies represent a significant shift in how we think about buildings, energy generation, and environmental sustainability. BIPV involves seamlessly integrating solar panels into various architectural elements such as roofs, walls, windows, and facades. This integration not only generates electricity but also enhances the aesthetic appeal of buildings.
BIPV relies on a range of solar cell materials, including monocrystalline, polycrystalline, thinfilm, and emerging technologies like perovskite solar cells. Advances in these materials have led to increased efficiency and flexibility in BIPV applications. Transparent and semi-transparent solar materials allow architects to incorporate solar elements without compromising the building's visual appeal. BIPV materials are available in various colors, sizes, and transparency levels to match different architectural styles.
BIPV systems generate clean, renewable electricity from sunlight, reducing reliance on fossil fuels and lowering carbon emissions. BIPV can improve a building's energy efficiency by reducing the demand for grid-supplied electricity, leading to cost savings over time. BIPV seamlessly blends with building designs, offering architects and builders creative freedom while meeting sustainability goals. BIPV materials come in versatile designs, allowing for aesthetically pleasing and customized solutions that cater to various architectural preferences. Buildings with BIPV installations tend to have increased property values due to their energy efficiency and sustainable features.
The future of BIPV technologies is promising. As solar cell efficiency improves and production costs decrease, BIPV is becoming more accessible to a wider range of construction projects. Moreover, advancements in energy storage and grid integration will enhance the reliability and autonomy of BIPV systems. Incorporating artificial intelligence and smart building technologies will enable BIPV systems to optimize energy generation and consumption. Furthermore, innovative financing models and government incentives may drive greater adoption of BIPV in both residential and commercial buildings.

## IV.CONCLUSION

In conclusion, the implementation of Building Integrated Photovoltaics (BIPV) within our project represents a significant stride toward sustainable, energy-efficient, and aesthetically appealing building design. Throughout this project, we have witnessed the transformative power of BIPV technologies, as they seamlessly blend architectural elegance with clean energy generation. By harnessing the power of sunlight to generate electricity, our BIPV system significantly reduces our reliance on non-renewable energy sources, thereby decreasing carbon emissions and mitigating our environmental footprint. The project aligns with our commitment to combat climate change and foster a greener, more sustainable future.
Our BIPV installation not only generates clean energy but also contributes to improved energy efficiency within our building. This synergy between energy generation and consumption not only benefits the environment but also translates into long-term cost savings. We have successfully demonstrated that BIPV can enhance the architectural aesthetics of our building. The incorporation of BIPV materials into various elements of our structure complements the overall design while harnessing the sun's energy, proving that sustainability and visual appeal need not be mutually exclusive.
However, it is important to acknowledge that BIPV projects are not without challenges. Proper planning, regulatory compliance, skilled installation, and ongoing maintenance are imperative to ensure the long-term functionality and performance of the BIPV system (Abigo et al, 2019).

## V. REFERENCES

[1] Abigo, I., Okwu, I. & Nkoi, B. (2019). Application Of Artificial Neural Network In Optimization Of Soap Production. World Journal of Engineering Research and Technology. Vol. 5 Pages 128-138.

[2] Abigo, I., Faisal, T., Iwan, M., Al-Assadi, H.M., & Ramli, H. (2012). Programming ABB Industrial Robot for an Accurate Handwriting. Latest Advances in Systems Science and Computational Intelligence. Pages 80-85.

[3] Bojić, M., Radulović, J., Nikolić, D., Miletić, I. (2015). Flexible Thin-Film Photovoltaic Technologies: In Building Integration, Proceedings of COST TU1205 Symposium Combined with EURO ELECS 2015 Conference, Guimaraes, Portugal, 120-127, ISBN 978-9963-697- 17-5.

[4] Ferrara, C., Wilson, H.R., Sprenger, W. (2017). Building-integrated photovoltaics (BIPV). The Performance of Photovoltaic (PV) Systems, 235-250.

[5] Global Solar, (2015), http://www.globalsolar.com/ [6]Kessler, F., Rudmann, D. (2004). Technological aspects of flexible CIGS solar cells and modules, Solar Energy 77, 685–695

[7] Nikolic, D., Skerlic, J., Miletic, M., Radulovic, J., Bojic, M. (2012), Energy optimization of PV panels size at Serbian ZNEB and PNEB, Conferinta nationala cu participare internationala instalatii pentru constructii si confortul ambiental, Editia 22, Timisoara, Romania, 226-234, ISSN 1842 – 9491.

[8] Pagliaro, M., Ciriminna, R., Palmisano, G., (2008), Flexible Solar Cells, Chemistry and sustainability, energy and materials, 1, 880 – 891.

[9] Radulovic J., Bojic M., Nikolic D., Skerlic J. (2014), Thin film photovoltaic technologies: status and perspectives, 45. International Congress and Exhibition on Heating, Refrigerating and AirConditioning, Belgrade.

[10] Radulović, J., Bojić, M., Nikolić, D., Skerlić, J., Taranović, D. (2013). The use of PV in netzero energy buildings: challenges and perspectives. 11th International Conference on Accomplishments in El. and Mechan. Engineering and Information Technology, 797-802.

[11] Razykov, T.M., Ferekides, C.S., Morel, D., Stefanakos, E., Ullal, H.S. (2011). Solar photovoltaic electricity: Current status and future prospects. Solar Energy 85, 1580–1608

[12] Tyagi, V.V., Nurul Rahim, A. A., Rahim, N.A., Jeyraj, A., Selvaraj, L. (2013). Progress in solar PV technology: Research and achievement. Renewable and Sustainable Energy Reviews 20, 443– 61

[13] Peters, I. M., Rodriguez Gallegos, C. D., Sofia, S. E., and Buonassisi, T. (2019). The value of efficiency in photovoltaics. Joule 3, 2732–2747. doi:10.1016/j.joule.2019.07.028

[14] Tripathy, M.; Sadhu, P. K.; Panda, S. K. (2016). "A critical review on building integrated photovoltaic products and their applications". Renewable and Sustainable Energy Reviews. 61: 451–465. doi:10.1016/j.rser.2016.04.008. ISSN 1364-0321

[15] Traverse, Christopher J.; Pandey, Richa; Barr, Miles C.; Lunt, Richard R. (2017). "Emergence of highly transparent photovoltaics for distributed applications". Nature Energy. 2 (11): 849–860.

[16] Abojela, Zuher & Mat Desa, Mohd Khairunaz & Sabry, Ahmad. (2023). Current prospects of building-integrated solar PV systems and the application of bifacial PVs. Frontiers in Energy Research. 11. 10.3389/fenrg.2023.1164494.

[17] Fernandes, Karen & Reddy, Y.V.. (2020). Energy Consumption and Economic Growth in Newly Industrialised Countries of Asia. International Journal of Energy Economics and Policy. 10. 384-391. 10.32479/ijeep.9678.

[18] Taylor, J., & Klenk, N. (2018). The politics of evidence: Conflicting social commitments and environmental priorities in the debate over wind energy and public health. Energy Research & Social Science, 47, 102-112.

[19] Wang, Y., Wang, D., & Liu, Y. (2017). Study on Comprehensive Energy-saving of Shading and Photovoltaics of Roof Added PV Module. Energy Procedia, 132, 598-603. https://doi.org/10.1016/j.egypro.2017.09.672.

[20] Traverse, C. J., Pandey, R., Barr, M. C., & Lunt, R. R. (2017). Emergence of highly transparent photovoltaics for distributed applications. Nature Energy, 2(11), 849-860. https://doi.org/10.1038/s41560-017-0016-9.

[21] Pagliaro, M., Ciriminna, R. and Palmisano, G. (2008), Flexible Solar Cells. ChemSusChem, 1: 880-891. https://doi.org/10.1002/cssc.200800127